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COAL GASIFICATION SYSTEMS ENGINEERING AND ANALYSIS FINAL REPORT APPENDIX E - COST ESTIMATION AND ECONOMIC EVALUATION METHODOLOGY

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CHAPTER I
SUMMARY OF METHODOLOGY

The Cost Estimation and Economic Evaluation methodologies presented below are consistent with industry practice for assessing capital investment requirements and operating costs of coal conversion systems. They are also directly responsive to guidelines stipulated in Section 5 of the Design Criteria for Conceptual Designs and Assessments of TVA's Coal Gasification Demonstration Plant, Tennessee Valley Authority, February 22, 1980. In addition, they are compatible with the ESCOE Guidelines for Economic Evaluation of Coal Conversion Processes, FE-2468-44, April 1979. All values stated herein are based on January 1980, dollars with appropriate recognition of the time value of money.

Evaluation of project economic feasibility can be considered a two step process (subject to considerable refinement). First, the costs of the project must be quantified and second, the price at which the product can be manufactured must be determined. These two major categories are discussed in Chapter II, COST ESTIMATION and Chapter III, ECONOMIC EVALUATION.

The basic methodology has two significant references:

(1) K. M. Guthrie, PROCESS PLANT ESTIMATING AND CONTROL, Craftsman Book Company of America, Solana Beach, California (1974).

(2) American Telephone and Telegraph Company, ENGINEERING ECONOMY, McGraw-Hill Book Company, New York, New York (1952).

The following summary of methodology has been divided into five parts:

(1) Systems Costs,

(2) Instant Plant Costs,

(3) Annual Operating Costs,

(4) Escalation and Discounting Process, and

(5) Product Pricing.

More detailed explanations are the subject of Chapters I and III.

A. SYSTEM COSTS

System costs are generated in one of two ways:

(1) A reference system cost is scaled to the required TVA capacity. A scaling exponent, e, is determined for each system:

$$\text{TVA System Cost} = \text{Reference Systems Cost} \times \left(\frac{\text{TVA Capacity}}{\text{Reference Capacity}}\right)^{e}$$

(2) The total installed cost can be determined as the sum of direct and indirect costs:

Total installed cost = Direct costs + Indirect costs

= (1 + Indirect cost factor) x Direct Costs

The first approach is demonstrated in Table I-1. The key to the method is selection of the scaling exponent. In the analysis presented in this report, the value of the exponent was obtained from Guthrie or based on engineering judgment.

The second method of determining direct and indirect costs was Guthrie or equivalent data to generate equipment costs. System costs are then obtained by applying indirect cost factors to total equipment cost. Table I-2 demonstrates this approach. Table I-3 contains the indirect cost factors. These are revised values of the factors found in Guthrie and the methodology document. The revisions reflect (1) the lack of taxes and insurance charge on the TVA facility, and (2) an effort to systematize and simplify the calculations by using common values for factors with small differences in this application.

This method of costing may be done at the system or subsystem level. Subsystem costs can be accumulated and assigned individual process contingencies in order to develop a system cost.

B. INSTANT PLANT COSTS

Instant plant costs are expressed as Total Capital Requirements. This cost consists of:

(1) Total facility investment,

TABLE I-1. SAMPLE SYSTEM COSTING BASED ON REFERENCE SYSTEM COSTS AND RELATED CAPACITIES

SYSTEM COST DATA

PROCESS:	KOPPERS-TOTZEK
SYSTEM:	4-ACID GAS REMOVAL - SELEXOL
UNIT OPERATION NUMBER:	22
SUBSYSTEM:	N/A
REFERENCE SOURCE FOR COSTING:	EPRI AF-916
REFERENCE SYSTEM COST:	$54,227,000 (mid-'76 DOLLARS)
REFERENCE CAPACITY:	407,775 ACFH
TVA CAPACITY:	289,436 ACFH
RECOMMENDED CAPACITY EXPONENT:	0.6

EXPLANATORY COMMENTS:

The reference system contains 3 parallel trains. Reference capacity equals 1/3 of reference system. TVA requires one train.

COMPUTATION METHOD:

TOTAL SYSTEM COST = 1/3 x REFERENCE SYSTEM COST x CAPACITY FACTOR x ESCALATION FACTOR

INPUTS:

REFERENCE SYSTEM COST: $\$54.227 \times 10^6$ (MID-'76 DOLLARS)

CAPACITY FACTOR: $\left(\frac{289,436}{407,775}\right)^{0.6} = .814$

ESCALATION FACTOR: 1.30 (TO JANUARY '80 DOLLARS)

RESULTS:

TOTAL SYSTEM COST = $19,130,081 (JANUARY '80 DOLLARS)

TABLE I-2. SAMPLE SUBSYSTEM COSTING BASED ON EQUIPMENT COST

SYSTEM COST DATA

PROCESS:	KOPPERS-TOTZEK
SYSTEM:	17 - COOLING WATER SYSTEM
UNIT OPERATION:	39
SUBSYSTEM:	BLOWDOWN TREATMENT
REFERENCE SOURCE FOR COSTING:	ENGINEERING IN-HOUSE COST ESTIMATE
REFERENCE SUBSYSTEM COST:	\$932,617 JANUARY '80 DOLLARS (TOTAL DIRECT COSTS)
REFERENCE CAPACITY:	N/A
TVA CAPACITY:	46 gpm
RECOMMENDED CAPACITY EXPONENT:	N/A

EXPLANATORY COMMENTS:

SUBSYSTEM CONSISTS OF 1 VAPOR COMPRESSION
EVAPORATOR (INSTALLED) = \$932,617

COMPUTATION METHOD:

TOTAL SUBSYSTEM COST = TOTAL DIRECT COST x (1 + INDIRECT COST FACTOR)

INPUTS:

TOTAL DIRECT COST = \$932,617 JANUARY '80 DOLLARS

INDIRECT COST FACTOR = 0.36 (ASSUMED "NORMAL" L/M RATIO)

RESULTS:

TOTAL SUBSYSTEM COST = \$1,268,359 (JANUARY '80 DOLLARS)

TABLE I-3. SUMMARY OF INDIRECT CONSTRUCTION COST ASSUMPTIONS

COST FACTORS	SYSTEM CHARACTERIZATION			
	SOLIDS HANDLING e.g. COAL. HANDLING	MIXED PROCESS e.g. GASIFIER "NORM$_1$"	CHEMICAL PROCESS e.g. ACID GAS REMOVAL	FACILITY "NORM"
L/M RATIO	.25	.36	.365	.36
MATERIALS/LABOR RATIO	80/20	75/25	75/25	75/25
CONSTRUCTION OVERHEAD$_1$	.18	.22	.23	.23
ENGINEERING HOME OFFICE$_1$	.105	.10	.10	.10
FREIGHT, TAXES, INSURANCE$_2$	.05	.04	.04	.04
TOTAL % OF TOTAL DIRECT COSTS (E+M+L)	.335	.36	.37	.36

1 ESTIMATE BASED UPON ADJUSTED GUTHRIE COST FACTORS - SEE p.6 METHODOLOGY

2 ESTIMATES BASED UPON ADJUSTED RICHARDSON RAPID SYSTEM DATA

(2) Other capital costs,

(3) Working capital, and

(4) Land costs.

1. <u>Total Facility Investment</u>

The Total Facility Investment consists of:

(1) Total system capital investment (TSCI),

(2) Project contingency (PC) (15% of TSCI),

(3) Contractor's fee (CF) (4% of TSCI + PC), and

(4) Owner's cost (2% of TSCI + PC + CF).

2. <u>Other Capital Costs</u>

The category of "Other Capital Costs" includes:

(1) <u>Paid-up royalties</u> - 0.5% of Total Facility Investment, incurred on the first day of operations.

(2) <u>Start-up and testing</u> - This cost is assumed to be incurred at a rate that is a linearly increasing proportion of the annual O+M, feedstock, catalyst, and chemical cost. The rate starts at zero at the beginning of start-up and testing and reaches 100% of the annual costs just cited at the end of the process.

(3) <u>Allowance for funds used during construction</u> (<u>AFUDC</u>) - The AFUDC was computed assuming a 12% cost of capital on:

   (a) average cumulative construction expenditures by module from beginning of construction of the module to start of module operations.

   (b) average cumulative start-up and testing expenditures.

   (c) land cost, assuming all costs are incurred on first day of project.

There is no AFUDC for paid-up royalties, since those charges are assumed to be paid on the first day of operations.

3. <u>Working Capital</u>

Working capital, a non-depreciable cost, consists of:

(1) <u>Initial charge of catalysts and chemicals</u> - This requirement was established during the engineering design effort. The values are identified for the worksheets in Section III.

(2) Materials inventories - 30 days supply of feedstock and make-up chemicals.

(3) Spare parts inventories - 1% of equipment and materials, or .0055 of total system cost based on the norm case for labor, materials, and equipment cost as shown in Table I-3.

(4) Minimum cash balance - 45 days of O+M and feedstock expenses, or .137 of O+M and feedstock annual expense.

4. Land Costs

Land is considered non-depreciable, and is assumed to cost $3,000 per acre. Land improvements are depreciable and are obtained from Mittelhauser Corporation guidelines.

C. ANNUAL OPERATING COSTS

The annual operating costs consist of O+M, feedstock, and catalyst and chemical costs. Net annual operating costs include by-product credits which affect the costs. The costs and by-product credits were computed per module as follows:

(1) Feedstock, catalyst and chemical make-up - Requirements are obtained from the facility design data.

(2) Electricity and water - Requirements are obtained from facility design data. Water costs represent a levelized capital recovery for pumps and piping to transport water into the facility from the TVA source. It is computed at $ .80/1,000 gal based on past construction experience.

(3) Operating labor - This is the summation of system operating labor requirements for each process. Rates are obtained from the TVA design criteria.

(4) Operating supplies - 15% of operating labor costs.

(5) Maintenance labor and supplies - This is obtained by dividing Total Facility Investment by four to spread costs across the four modules, and then multiplied by .04. There is a 40/60 split between labor and supplies.

(6) Supervision - Derived system by system in design effort. TVA design criteria specify rates.

(7) General plant staff - 30% of all other labor.

(8) Administration and general overhead - 5% of all other O+M costs.

Details are shown in the worksheets in Section III.

D. ESCALATION AND DISCOUNT PROCESS

The TVA design criteria contained in the Methodology document were followed in computing escalation. A 12% discount rate was used, also consistent with the TVA specifications.

E. PRODUCT PRICING

Two measures of product price have been derived: the 1980 product price and the UAE cost of service price. The methodology for each is reviewed here.

1. Computation of a "1980 Price"

For certain economic evaluation purposes, it is convenient to define a 1980 price, which has the following interpretation:

(1) In the absence of inflation, assume that the price received is the 1980 price in all time periods.

(2) In the presence of inflation, assume that the price received on each time period is the 1980 price escalated to that time period by the general rate of inflation.

Then, the discounted present value of revenue equals the present value of the plant, as defined earlier.

The 1980 price is computed as follows. Let:

PV = present value of the plant in January 1980.

D = Nominal discount rate

R = Real discount rate

E = general rate of inflation = $[(1+D)/(1+R)] - 1$

P_{1980} = 1980 price of product
MAP = module annual production
PV_i = present value of i^{th} module
S_i = date of start-up of the i^{th} module from January 1980, in years $S_1 = 5.5$ $S_3 = 7.0$
$S_2 = 6.5$ $S_4 = 7.5$

For the TVA coal gasification plant, the 1980 price satisfies the following equation, (assuming all revenue for a year is received at the end of the year; a slightly different answer would be obtained by assuming monthly or continuous revenue)

$$PV_{Facility} = PV_1 + PV_2 + PV_3 + PV_4$$

$$PV_{Revenue} = \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_1+i}} + \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_2+i}} + \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_3+i}}$$

$$+ \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_4+i}}$$

$$= P_{1980} \times MAP \times \left[\frac{1}{(1+R)^{S_1}} + \frac{1}{(1+R)^{S_2}} + \frac{1}{(1+R)^{S_3}} + \frac{1}{(1+R)^{S_4}}\right] \sum_{i=1}^{20} \frac{1}{(1+R)^i}$$

Evaluating this expression for R = 4.7% (D = 12%; E = 7%);

$$PV = P_{1980} \times MAP \times 37.67$$

or $$P_{1980} = \frac{PV}{MAP \times 37.67}$$

2. <u>UAE Cost of Service Price</u>

The UAE cost of service is computed using the following three steps:

(1) Costs are escalated according to the TVA design criteria.

(2) Costs are discounted to a 1980 present value using a 12% discount rate.

(3) Costs are annualized over the life of the plant a a 12% rate.

The UAE cost of service price is computed using the same formula as the 1980 product price, using the nominal discount rate rather than the real discount rate, yielding the following expression:

$$PV = UAE \times MAP \times \left[\frac{1}{(1+D)^{S_1}} + \frac{1}{(1+D)^{S_2}} + \frac{1}{(1+D)^{S_3}} + \frac{1}{(1+D)^{S_4}} \right] \sum_{i=1}^{20} \frac{1}{(1+D)^{i}}$$

Evaluating this expression for D = 12% and

$S_1 = 5.5$ years $\qquad S_3 = 7.0$ years

$S_2 = 6.5$ years $\qquad S_4 = 7.5$ years

$$PV = UAE \times MAP \times 14.152$$

or

$$UAE = \frac{PV}{MAP \times 14.152}$$

CHAPTER II
COST ESTIMATION

A. INTRODUCTION

The Cost Estimation portion of these methodologies is divided into two segments. They are the Estimation of Total Capital Requirements and the Estimation of Annual Operating and Maintenance Expenses.

The validity of any estimate, however, depends upon close attention to site specific process requirements and conditions, knowledge of special materials and particular equipment requirements. Development of cost estimates from the translation of historical or published data must take cognizance of these exact requirements if the estimates are to be useful for project evaluation and planning.

B. ESTIMATION OF TOTAL CAPITAL REQUIREMENTS

The purpose of the TVA Coal Gasification Demonstration Plant is to resolve commercial investment uncertainties by establishing the actual economic factors, environmental feasibility, capital and resource requirements, constraints and product markets, as well as encouraging the creation of a viable gasification industry using this technology. The modular approach postulated for this commercial demonstration plant allows for developmental resolution of scale-up problems in the first module and application of the improved technology to the succeeding modules. Upon completion, the facility will produce commercially significant volumes of merchantable products.

The basis and assumptions applicable to investment requirements, from Section 5 of the TVA document, are reproduced in Appendix B and result in a schedule illustrated in Table II-1.

The elements of estimating total capital requirements are:

(1) Land and Land Related Costs

(2) Process Plant Systems (Modules 1, 2, 3 and 4)

TABLE II-1. CONSTRUCTION SCHEDULE AND INVESTMENT ASSUMPTIONS

I. CONSTRUCTION SCHEDULE AND OPERATING LIFE

		MOD 1	MOD 2	MOD 3	MOD 4
DESIGN & CONSTRUCTION	BEGIN	10-01-80	10-01-81	04-01-82	10-01-82
	END	12-31-84	12-31-85	06-30-86	12-31-86
START-UP AND TEST					
SYSTEMS	BEGIN	09-01-83	09-01-84	03-01-85	09-01-85
	END	12-31-84	12-31-85	06-30-86	12-31-86
MODULE	BEGIN	01-01-85	01-01-86	07-01-86	01-01-87
	END	06-30-85	06-30-86	12-31-86	06-30-87
START COMMERCIAL PRODUCTION		07-01-85	07-01-86	01-01-87	07-01-87
RETIRE MODULE		06-30-05	06-30-06	12-31-06	06-30-07

II. BASIS

1. INVESTMENT REQUIREMENTS TO BE STATED IN JANUARY 1980 DOLLARS.

2. CAPITALIZATION: ALL EQUITY FINANCING; APPROPRIATION.

3. SITE COSTS
   a. LAND = $3000/ACRE
   b. CLEARING AND GRUBBING = $2000/ACRE
   c. EXCAVATION: EARTH = $1.50/YD^3; STONE = $10/YD^3; FILL = $3/YD^3.

4. CONSTRUCTION LABOR
   a. RATES, 1980, PER TABLE B.5 OF APPENDIX B
   b. ESCALATION RATES (1-1 THROUGH 12-31)
      1980 - 8.5%
      1981-1985 - 9.0%/YR
      1986 - 8.0%/YR

5. CONSTRUCTION MATERIALS AND EQUIPMENT ESCALATION RATES*
      1980 - 1.00 (BASE AS OF 1/1/80)
      1980 - 10%
      1981-1985 - 9.5%/YR
      1986+ - 8.0%/YR

(3) General Facilities Systems

(4) Project Indirect Costs (applied by system)

(5) Process Contingencies (applied by system) and Project Contingency (applied to facility)

(6) Total Installed Plant

(7) Contractor's Fee

(8) Owner's Costs

(9) Other Capitalized Costs

(10) Working Capital.

The basis and assumptions for each element follows.

1. <u>Land and Land Related Costs</u>

The acquisition price of the necessary site include battery-limits, offsites, general and service facilities. For purposes of this estimate, the total land is assumed to be purchased on the first day of project implementation, i.e., design/construct Module 1.

Area requirements and site preparation requirements are determined from the specific processing and offsite configurations and valued at the $3,000 per acre specified in Design Criteria Section 5 guidelines.

2. <u>Process Plant Systems</u>

Major equipment items are assigned a dollar value from vendor's quotes, cost data base material in existing files, other published materials, or from the Guthrie or Richardson's basic cost reference data. Equipment costs are a function of size, temperature, pressure, special material requirements and complexity. Each generic type of equipment has a particular pattern of field materials and installation labor dependent upon those same process conditions and the type of equipment. In general, the Guthrie method for adding the costs of field materials, installation and erection of materials and equipment is employed. Suitable adjustments are made for certain materials or operating conditions to assure recognition of process-specific circumstances. The resultant sum represents installed facility system or subsystem costs. Incorporated in the estimates are process contingencies applied to those segments not yet commercially or technologically proven.

The summation of all segments of the processing facility represents estimated costs of equipment, field materials and construction labor, stated separately, which constitute the process plant.

3. General Facilities Systems

Each candidate plant has a requirement for buildings, storage, utilities, yard piping and auxiliaries which are necessary to serve the process but do not enter the main process stream. Conceptually, some of these support items may be initially installed with capabilities of serving some or all of the ultimate processing capacity. General facilities estimates include costs for site development and preparation.

The cumulative total costs of process plant and general facilities represent the total installed cost for the candidate process and are segregated by equipment, materials and labor.

4. Project Indirect Costs

The total installed costs above are incomplete, representing only some 60% to 70% of the required construction expenditures. These direct costs require support services during construction. Allocated or indirect construction costs, discussed below, are individually sensitive to labor-intensity or materials-intensity. The discussion which follows is general in nature and includes some items, e.g., fringe benefits, which are omitted from this task because they are already incorporated in hourly construction labor costs specified by TVA. Another redundant item of indirect expense is the sales tax on required materials which is assumed inoperative for this review. Indirect costs are defined as those costs incurred by a construction prime-contractor for project management, engineering, procurement, field supervision, general overhead expenses and other costs. They can be generalized and segregated into three broad classifications: Construction Overhead Expenses, Engineering and Home Office Costs, and Freight, taxes, duties and insurance.

a. Construction Overhead

This category includes field supervision, temporary facilities during construction, equipment rental and construction services like cleanup, security, medical, expendable supplies, public liability and

damage insurance, etc. It also includes fringe benefits and labor burden which comprise almost half. These items are related to direct field labor but are adjusted, by a labor to materials ratio, to serve as a multiplier for installed costs. Table II-2 is presented from Guthrie and is adjusted for significant increases between 1970 and 1978 in the union-contract health and welfare, pension, vacation, education, FICA, Federal Unemployment Insurance, State Unemployment Insurance and Workmen's Compensation Insurance. As a part of the total project indirects construction overhead is customarily stated as a percentage of (material plus labor) so is adjusted to reflect the appropriate L/M ratio in Table II-3. Table II-4 is similar to Table II-3 except that it provides a summary of indirect construction cost assumptions by system characterization.

b. Engineering and Home Office Costs

The cost of contractor engineering and office support is directly related to the dollar value of equipment plus materials in the project. For conceptual design estimating purposes, it has been assumed that the relationships illustrated in Guthrie's itemized listing are still valid. Table II-2 presents Guthrie's engineering costs as a function of the M/L ratio. These percentages are then shown in Table II-3 as part of the total indirect construction costs.

c. Freight, Taxes, Duties and Insurance

Freight on materials delivered to the plant site is estimated from Richardson Rapid Systems extensive tariff data; account 100-700, V.4; at 4.3% of the material price. Sales or other taxes are assumed at 5% of the sale price and insurance is estimated to cost approximately 1-1/4% of the value of the material for a total of 10.55% of the material cost. These have been adjusted for L/M ratio and included in the summary table (Table II-3). This table has been modified from the previous document BDM/W-80-258-TR-RV1 to reflect the elimination of taxes and insurance for the TVA gasification project.

5. Process Contingencies and Project Contingency

Regardless of the level of technological development, every construction project requires an allowance for contingencies to accommodate

TABLE II-2. CONSTRUCTION OVERHEAD AND ENGINEERING INDIRECT COST FACTORS

	Percent Direct Labor	L/M Ratio 1.00	0.66	0.36	0.25	0.18
Construction Overhead Cost						
Direct Material/Labor		50/50	60/40	75/25	80/20	85/15
Fringe Benefits Labor Burden	46.4	23.3	18.6	11.4	9.5	7.0
Field Supervision	12.0	6.0	4.8	3.0	2.4	1.8
Temporary Facilities	6.0	3.0	2.4	1.5	1.2	1.0
Construction Equipment	10.0	5.0	4.0	2.5	2.0	1.5
Small Tools	2.4	1.2	0.9	0.6	0.5	0.4
Miscellaneous Field Costs	12.0	6.0	4.8	3.0	2.4	1.8
TOTAL	88.8	44.5	35.5	22.0	18.0	13.5
Factor F_c		2.0	1.6	1.00 "Norm"	0.8	0.6
Engineering Cost						
Direct Material/Labor		50/50	60/40	75/25	80/20	85/15
Project Management	1.9	0.8	1.1	1.3	1.4	1.5
Process Engineering	0.6	0.3	0.3	0.4	0.5	0.6
Design and Drafting	3.6	1.8	2.2	2.7	2.8	3.1
Procurement	0.4	0.2	0.2	0.3	0.3	0.4
Construction Services	0.2	0.1	0.1	0.1	0.1	0.1
Engineering Direct Labor	6.7	3.2	3.9	4.8	5.1	5.7
Office Indirects and Overhead Expense	6.9	3.3	4.1	5.2	5.4	5.8
TOTAL	13.6	6.5	8.0	10.0	10.5	11.5
Factor F_c		0.65	0.80	1.00 "Norm"	1.06	1.15

TABLE II-3. SUMMARY OF INDIRECT CONSTRUCTION COSTS

EXPRESSED AS A PERCENTAGE OF (E + M + L)

L/M RATIO	1.0	0.66	0.36	0.25	0.18
RATIO MATERIALS/LABOR	50/50	60/40	75/25	80/20	85/15
CONSTRUCTION OVERHEAD	44.5	35.5	22.0	18.0	13.5
ENGINEERING/HOME OFFICE	6.5	8.0	10.0	10.5	11.5
FREIGHT/TAXES/INSURANCE	2.5	3.0	4.0	5.0	5.5
RAW TOTAL % OF (E+M+L)	53.5	46.	36.0	33.5	30.5

TABLE II-4. SUMMARY OF INDIRECT CONSTRUCTION COST ASSUMPTIONS BY SYSTEM CHARACTERIZATION

COST FACTORS	SYSTEM CHARACTERIZATION			
	SOLIDS HANDLING E.G., COAL HANDLING	MIXED PROCESS E.G., GASIFIER	CHEMICAL PROCESS E.G., ACID GAS REMOVAL	FACILITY
	"NORM[1]"			"NORM[2]"
L/M RATIO	.25	.36	.365	.36
MATERIALS/LABOR RATIO	80/20	75/25	75/25	75/25
CONSTRUCTION OVERHEAD[1]	.18	.22	.23	.22
ENGINEERING HOME OFFICE[1]	.105	.10	.10	.10
FREIGHT, TAXES, INSURANCE[2]	.05	.04	.04	.04
TOTAL % OF TOTAL DIRECT COSTS (E+ M+ L)	.335	.36	.37	.36

1 ESTIMATE BASED UPON ADJUSTED GUTHRIE COST FACTORS - SEE PAGE 6 METHODOLOGY

2 ESTIMATES BASED UPON ADJUSTED RICHARDSON RAPID SYSTEM DATA

unpredictable price fluctuations, overlooked components and malfunctioning equipment. The process contingency is applied to systems costs and varies between 0% and 30% depending on the "hardness" or "softness" of the system cost estimation. The project contingency is applied as a percentage of cumulative facility expenditures. A project contingency of 15% has been assigned to the entire facility.

6. Total Installed Plant

The Total Installed Plant is defined as the summation of process plant, general facilities, indirect construction costs and project contingency. It is perhaps most readily visualized as the total contractor's costs over construction.

7. Contractor's Fee

Previous factors have included all costs incurred by the contractor but have avoided any consideration of the contractors profit or return. Generally based upon the total volume of money handled/disbursed by the contractor, contractor's fee is conventionally applied as a percentage of Total Installed Plant and is usually in the range of 3.5% to 5% of that amount. The study team has used a rate of 4% for contractor's fee.

8. Owner's Costs - Engineering General and Administrative

During any extended construction period, the owner/operator bears costs directly related to the particular facility. There are costs involved in engineering and construction monitoring, contractor liaison, permits and fees, expediting and controlling construction cash flows. Conventionally, this is taken as a percentage of the total installed plant costs and contractor's fee. Sensitive to the labor/material ratio and total projected costs, this percentage can range between 2% and 3% of the total installed plant costs for the type of project visualized herein. The study team has used 2% of Total Installed Plant and Contractor's Fee in its calculations.

9. Other Capitalized Costs

There are basically three components of capitalized costs to be considered. These are costs incurred that are vital to a smooth project start-up and they are traditionally accumulated as a capital item and amortized over the life of the project for recoupment.

a. Paid-Up Royalties

Paid-up Royalties represent a fee paid to a licensor for the right to design, use and operate a patented process proportioned to the size and throughput of a licensed unit. These do not significantly affect the level of total capital requirements although they may be a substantial single sum. Specific values may not be readily available and a reasonable approximation may be required. Paid-up royalties have been assumed to be 0.5% of Total Facility Investment, incurred on the first day of operations.

b. Start-Up and Test

In accordance with the prescribed construction schedule, each module will require about 22 months to purge, start-up, test and finalize. During this period, segments of the module will operate individually and collectively until the full module is operations ready. Necessarily, operating and maintenance workers, with related supplies and expenses, utilities, catalysts and chemicals and feedstock will be required. The expenses incurred are assumed to increase linearly over the period from start-up to acceptable testing and thus will be equivalent to eleven (11) months of design rate operations (see assumed construction schedule in Table II-1). These costs are capitalized and recovered through amortization over the life of the project, contributing to revenue requirements during the project lifetime.

c. Allowance for Funds Used During Construction

Investment in operating facilities is an expenditure made before any revenues can be generated, with an objective of earning future returns as well as recovering the initial investment. Accordingly, this committed capital accrues imputed current earnings during the construction period which are aggregated as a part of total capital requirements and amortized or depreciated over the project lifetime as a portion of capital related charges to annual operations.

The AFUDC amount is a function of the cost of capital rate (12%), the length of the construction period and the level of cumulative expenditure for the module. The cumulative levels of expenditure are interpreted from a sigmoidal curve recently used by DOE, given the stated

construction period and cost of capital. During each annual period, it is assumed that the expenditures are made linearly for computation of the construction interest. An exception is the site purchase. The expenditure for land is assumed to be made on the first day of implementation.

10. Working Capital

A non-depreciable constant capital commitment, working capital is defined by accountants as the excess of current assets over current liabilities. For project evaluation, the working capital sum is made up of several categories.

a. Initial Charge of Catalysts and Chemicals

This operating facility must maintain a design level of catalyst and process chemicals to sustain operations over its lifetime. Therefore the value of the initial placement represents capital committed to operations and, as such, will earn a return on this amount with the original amount theoretically recovered upon cessation of the facility.

b. Materials Inventories

To assure smooth reliable operations, it is vital that an inventory of feedstock, operating chemicals, and catalyst is maintained at the site. Maintenance of this inventory represents committed capital. Normally, the feedstock inventory is the most significant item and is derived on the basis of satisfying process requirements for a given number of design-operations days, on the order of 30 days. The value of the inventory, once commercial operations commence, is held constant over project life with no revisions due to intervening escalation.

c. Parts Inventories

Unpredictable equipment failures require that the plant maintain an inventory of spare parts for critical equipment. Additionally, expendable small tools must be on hand to facilitate operations and maintenance functions. The conventional allocation to this inventory amounts to 1% of the value of equipment and materials or 0.55% of total system cost.

d. Minimum Cash Balance

There is an inevitable time lag between generation of costs and receipt of revenues apportioned to those costs. During this period, the facility must maintain adequate cash reserves to pay the expenses. For

this estimate, it is assumed that sufficient cash reserves will be maintained to be equivalent to 45 days of net cash operating expenses (or 13.7% of O&M and feedstock annual expense).

11. Adjusted Total Capital Requirement

The Design Criteria require that the estimated Total Capital Requirement will be stated in terms of January 1980 dollars. With pre-start up expenditures accumulating until the middle of 1989 and intervening escalation of construction labor and equipment, materials and supplies it becomes necessary to annualize these future expenditures and convert them to their worth as of January 1980 by use of the common "present value of a future sum" factor for the proper number of years at the stated 12% cost of capital rate. The derived 1980 cost equivalent will serve as the basis for capital recovery and capital related charges over the project lifetime.

As an important note, the replacement costs of certain worn-out, failed equipment are incorporated in the Total Capital Requirements. Normal life expectancy, rigorous operating conditions and inherent material/structural characteristics may require interim replacement(s) during the module or facility life and these capital obligations must be recognized to assure an equitable comparison.

C. ESTIMATION OF ANNUAL OPERATING AND MAINTENANCE EXPENSES

The objective of this task is to develop a compatible framework so that the economic attributes of several candidate coal gasification processes can be compared on a side by side basis. Elements of these economic characteristics can be divided into two major classifications; capital related and operations related. The total capital requirements have been discussed earlier, in Section 1, and those data are used in capital related charges to operations in Section 2, such as maintenance expenses conventionally derived as a percentage of plant investment. This is done because the maintenance charges reflect capital equipment but are not properly characterized as capital costs.

Operations related cost characterization of any process is most easily identified as all the goods and services that are required to make installed facilities perform reliably over their projected lifetime. It involves generic groupings such as feedstock, fuel, water, power, catalysts and chemicals necessary for operations and it also involves the people necessary to operate and maintain those operations.

The elements of annual operating and maintenance expenses and credits are:

(1) Feedstock Costs
(2) Catalyst and Chemicals
(3) Process Utilities
(4) Operating Labor
(5) Operating Supplies
(6) Maintenance Labor
(7) Maintenance Supplies
(8) General and Administration Expenses
(9) By-Product Revenues.

1. <u>Feedstock Costs</u>

The Design Criteria establishes costs for coal delivered to the plant in 1980 with prescribed cost escalation rates over time. The nominal rate of feed is 5,000 TPD of coal to each module and thus costs could be assigned on an annual basis. However, the volume of coal delivered to the gasifier may vary from process to process. Process fuel requirements will differ, and certain processes may not be adaptable to use of fines generated in the feed preparation. Accordingly, although the delivered cost of coal may be the same for each process, the value of feedstock delivered to the gasifiers may be different.

2. <u>Catalyst and Chemicals</u>

Catalyst which may be used in operations is generally relatively expensive on a unit basis but normally has some guaranteed lifetime exceeding an annual period. The estimated cost for a complete charge of catalyst has been pro-rated on an annual basis for presentation in the estimated

annual operating and maintenance expenses. Chemical consumption over the year has been derived from processing requirements and from operational plants with similar designs.

3. Process Utilities

Process requirements established in the facility design produces estimates of fuel, steam, electric power, and water required to sustain annual operations at the mandated 90% plant capacity factor. Appropriate unit values are assigned to these annual volumes to determine their contribution to annual costs. The cost of electricity has been obtained from Table 5.1 of the Design Criteria. Water costs represent a levelized capital recovery for pumps and piping to transport water into the facility from the TVA source. It is computed at $.80 per 1,000 gallons based on past construction experience.

4. Operating Labor

Particular segments of the facility are more labor-intensive than others in normal operations. Under the guidelines established in the Design Criteria document, manpower requirements are minimized through installation of capital equipment. The pattern of operations staffing presented in Table 5.5 of that reference is followed, omitting only the student categories. From experience and published reports, a typical crew is established for each facility. The numbers and their individual wage-rates are then be used to derive a composite hourly wage rate which is the basis for deriving annual operating labor costs of the particular plant.

5. Operating Supplies

In any operating facility there are innumerable small items that contribute to annual operating expenses but do not warrant a detailed listing. These would include items like lubricating oil, wiping rags, small expendable hand tools, and other similar consumable materials. A conventional application of operating supplies as 15% of operating labor costs has been used.

6. Maintenance Labor

Customarily, maintenance costs for coal gasification facilities have been assigned as a percentage of facility investment. The level of

maintenance expense differs for various types of operating equipment and, thus, it is not feasible now to specify the rate to be applied at each plant. A total amount for maintenance labor and supplies is obtained by dividing Total Facility investment by four to spread costs across the four modules and multiplying by 4%. Conventional practices assign the total maintenance expenses on a 40% labor; 60% supplies ratio.

7. <u>Maintenance Supplies</u>

As discussed in 6. above, maintenance supplies are conventionally estimated to be a percentage of installed plant cost. The derived percentage for use, based upon specific operating characteristics, has been reviewed to assure a reasonable result.

8. <u>General and Administrative Expenses</u>

General and administrative expenses are factored as 5% of operations and maintenance less feedstock and chemicals to account for expected expenses necessary to service and administer the operating facility. Items financed from the G&A account include employee relations, accounting, purchasing and legal as well as outright expenditures for office supplies, and other general consumables.

9. <u>By-Product Revenues</u>

By stipulation, the only by-products assigned an economic value and credited against operations will be coal fines produced, collected and delivered to a purchaser at the plant fence and any excess electrical power generated at the facility. As specified, the coal fines will be sold at a value which is 80% of the unit delivered coal price. The electrical power will be valued at the energy price shown in the Design Criteria and previously discussed. The estimated revenues that will be generated by these salable by-products serve to reduce the total revenue requirements which must be met by the sale of product gas.

CHAPTER III
ECONOMIC EVALUATION

A. REVENUE REQUIREMENTS APPROACH

The methodology to be employed in the Economic Evaluation is the Cost of Service, or Revenue Requirements Approach, and is the technique described in Section 5 of the Design Criteria document. This method determines the product price that is required so that all costs are recovered. To clarify, calculation of a project's revenue requirements does not measure a project's revenues. The Cost of Service or Revenue Requirements Approach establishes costs, not revenues. To carry the distinction a step further than required for this analysis, forecast revenues that exceed costs computed using the Revenue Requirements Approach indicate an economically attractive candidate while projects that show costs greater than revenues should be avoided. Utilities, by their regulated nature and lack of direct regional competition, base their unit prices to customers on a Cost of Service method which must be certificated by the appropriate regulatory commission.

The Revenue Requirements Approach, as used by all jurisdictional utilities and regulatory agencies, include every cost of doing business. Normally, the components are total operating and maintenance expenses, allowable depreciation or capital recovery, a return on rate base (net undepreciated investment), and income taxes on the taxable portion of the return. By definition of the Design Criteria, there is no income tax applied to the operations contemplated in this study, so that the costs are the sum of operating expenses, depreciation and return on rate base. This can be further simplified into just two areas, annual costs and capital recovery.

Annual costs are conventionally held constant (at a constant dollar level) over project life. Thus, they represent a uniform annual charge which can be used without modification to determine uniform annual equivalent operating and maintenance cost per unit of annual product. The Design

Criteria economic basis and assumptions, however, impute cost escalation rates to the items in annual costs and, moreover, require that the uniform annual equivalent costs be stated in terms of January, 1980, dollars. The added complexity requires modifications to the traditional methodology which are discussed later, in general terms, under the category of escalation. The Design Criteria document, in Section 5, Basis and Assumptions for Economic Assessments (and Appendix B), structures the shape of the operating cost characterization by prescribing certain standards illustrated in Table III-1.

Capital Recovery, as noted before, includes the return <u>of</u> capital plus the return <u>on</u> capital. The annual depreciation charge to operations is the return <u>of</u> capital and is, in this study, based upon the customary straight line depreciation method whereby the total depreciable investment is divided by the number of years of project life to assign equal dollar charges to operations for each year. The return <u>on</u> investment, or return on rate base, represents earnings on investor's committed capital. The complete definition of return on committed capital includes debt interest expenses as well as a return on equity capital. The return on rate base or return on net undepreciated plant specifies a return on still-committed capital, i.e., capital that has not yet been recouped through depreciation charges. The allowable return on rate base may be amplified in that it represents an authorized rate of return multiplied by net rate base. The authorized rate of return or cost of capital rate is a composite weighted cost rate of long term debt and all forms of equity capital contained in the corporate capital structure. For this analysis, the cost of capital rate is stated to be 12% and the capitalization is a governmental appropriation, considered as equity capital herein. The cost of capital rate is used as the "discounting" rate when performing analyses which recognize the time value of money. In conventional constant-dollar studies, a capital recovery factor can be applied to total depreciable investment. This term quantifies the uniform annual equivalent capital recovery charge to operations. At the stated cost of capital and specified project life, it will precisely meet the requirements to recoup capital through depreciation and

TABLE III-1. BASIS AND ASSUMPTIONS FOR ECONOMIC ASSESSMENTS OPERATING AND MAINTENANCE EXPENSES

(1) Each module will have an operating life cycle of 20 years.

(2) Each module will operate annually at a plant capacity factor of 90%; i.e., it will operate an average of 328.5 days per year at design capacity.

(3) All operating cost estimates will be stated in terms of January 1980, dollars.

(4) There will be no annual property tax liabilities assessed for the facility because it will be owned (and operated) by the government. Although not addressed in the criteria, it is presumed that the project will be self-insured; i.e., there will be no expenses for insurance premiums.

(5) There will be general and administrative expenses inherent to the facility which will amount to 5% of the total operating and maintenance expenses. It is assumed that the stated "total operating and maintenance expenses" will not include the cost of coal feedstock requirements, for this purpose.

(6) Delivered Cost of Coal Schedule

1980 - Price is $\$1.25/10^6$ BTU
1981-1985 - Price escalates at 9%/yr rate
1986-1995 - Price escalates at 8%/yr rate
1996+ - Price escalates at 7%/yr rate.

(7) The delivered cost of limestone in 1980 will be $13/ST. The price will escalate under the same rates scheduled for coal feed.

(8) The delivered cost of coke, for gasifier start-up, in 1980 will be $60/ST. The price will escalate under the same rates scheduled for coal feed.

(9) There will be only 2 byproduct credits against revenue requirements in the base case. These credits will apply to coal fines generated in the feed preparation section of the plant and to any electric power generated which exceeds plant requirements and is exported from the plant. The coal fine sales will be valued at 80% of the delivered run of the mine coal feedstock price. Excess electricity will be valued at the price charged to the plant for externally supplied power. It is assumed the design criteria refers only to the energy charge in the electric power tariff presented.

TABLE III-1. BASIS AND ASSUMPTIONS FOR ECONOMIC ASSESSMENTS OPERATING AND MAINTENANCE EXPENSES (CONTINUED)

(10) Electric power costs to meet plant requirements are detailed in Table 5.1 of the Design Criteria Document, projected at annual escalation rates reflecting both cost escalation and TVA power system expansions.

(11) Plant operating labor wage rates as of 1980 are detailed in Design riteria Table B.4, Appendix B, and a typical manning chart is shown in Table B.4. These wage levels will escalate annually on a mid-year July 1 basis. Annual escalation rates will be 8% starting 7-1-80 and finishing after the 7-1-85 increase. Thereafter, annual escalation will be 7.5% on July 1 of each year.

(12) Maintenance labor wage rates, detailed in the Design Criteria Table B.3, are shown in terms of day to day activities and also in terms of the high-activity long-hour plant turnaround period when scheduled major maintenance is performed. Maintenance labor rates will escalate annually on a calendar basis from the 1980 hourly rates shown. In 1981 the escalation will be 9%, from 1982 through 1986 the increase will be 8.5%/yr, and at a rate of 7.5%/yr thereafter.

earn the required return on unrecovered capital. For clarification, the annual capital recovery charges are fixed when a given facility becomes a part of rate base, i.e., they do not escalate or vary over the life of the project.

In simplified form, the revenue requirement calculation for this assessment, in the absence of inflation, would be:

Uniform Annual Equivalent Revenue Requirements

Coal Costs	$\left[X\ TPYr^{(1)}\right] \times \left[\frac{y\ MMBTU}{TON}\right] \times \left[\frac{\$1.25}{MMTBU}\right]^{(2)} = \$K_1$
Sum of Other O&M Costs	$= \$O\&M$
Subtotal of Feedstock and Other O&M Costs	$\$K_1 + \$O\&M_2 = \$K_3$
Capital Recovery:	
Non-depreciable Investment:	$\$NDI \times 12\%^{(3)} = \$0.12\ NDI$
Depreciable Investment:	$\$DI \times (A/P,\ 12\%,\ 20)^{(4)} = \underline{\$0.1339\ DI}$
Total Uniform Annual Equivalent Revenue Requirements	$UAE = \$(K + 0.12\ NDI + 0.134\ DI)$
Annual Product, in MMBTU	P
Uniform Annual Equivalent Product Price/MMBTU	$= \frac{\text{Total UAE RR}}{P}$

(1) 5000 TPD x 365 day/yr x 0.9 prod. factor = 1.6425×10^6 TPYr.

(2) Specified 1980 coal price.

(3) Investment in Land, Working Capital, etc. that is recovered intact upon project retirement. As directed in the design criteria, the effect of recovery on revenue requirements is omitted.

(4) The time-value factor for capital recovery at 12% cost of capital over 20 years. Mathematically, it is derived as

$$\frac{0.12\,(1.12)^{20}}{(1.12)^{20} - 1}.$$

It is defined as a uniform annual series from a present sum. Commonly known as the Capital Recovery Factor, this includes return on net investment and depreciation.

B. ESCALATION AND DISCOUNT PROCESS

The imposition of escalation on annual costs, as an annual percentage or geometric progression, nullifies the straightforward constant dollar approach to the calculation of uniform annual equivalent revenue requirements. Similarly, the translation of future escalating dollar levels to January, 1980 values at the given time-value of money rate makes it impossible to perform the simple calculations. Accordingly, modifications to the calculation procedure are necessary to obtain the desired results. The following brief description illustrates the approach.

1. Construction Period: (Initial and/or Replacements)

Given: Base point - January, 1980 dollars and price level.

Estimate: Initial Estimated Total Capital Requirements

- assume 1980 dollars
- estimate equipment, materials and labor.

Allocate: Allocate Annual Construction Expenditures

- allocate from curve of cumulative expenditures vs. construction percentage.

($ Portion, Year k) = Capital Account Portion for Year k given in 1980 dollars)

<u>Escalate</u>: Escalate Annual Increments from Stolid Rates and Scheduled Time*

$\$P_{e,k}$ = (\$Portion, Year k) x (F/P, e%, Year k - 1980).

<u>Discount</u>: Discount into 1980 dollars*

Capital Requirement Present Value (\$1980) =
($\$P_{e,k}$) x (P/F, 12%, Year k - 1980).

As a simplification, the escalation and translation steps could be combined in one operation. The "real" discounting rate, or "convenience" rate named by AT&T, is derived as

$$i_r = [(1 + i)/(1 + e)] - 1$$

Present Value (\$1980) = (\$Portion, Year k in 1980 dollars from base estimate)
x (P/F), "i_r" rate, Year k - 1980)

However, it is of interest to note the total expenditure magnitude in current dollars and therefore the two step calculation was performed. These calculations will yield Total Capital Requirements, in current dollars and the present value in 1980 dollars.

2. <u>Operating Life</u>

The 20 year operating life for each module represents a series of identical inputs subject to intervening geometric escalation and therefore can be termed an escalating annuity. The initial estimate is presumed to be in 1980 dollars, for any given component of operating expenses. The uniform annual equivalent, in terms of 1980 dollars, is affected by the cost of capital, intervening escalation and future expenditures. The uniform annual equivalent is calculated as follows; for example, in the case where the O&M escalation rate changes after 5 years of operation:

let \$C = 1980 dollars; initial estimate of annual operating and maintenance expense component

* See Appendix A for definitions. Note that there may be multiple rates of intervening escalation. Briefly, F/P is the future value of a present amount, and P/F is the present value of a future sum.

e_1 = % escalation of O&M per year between 1980 and start of commercial operations

e_2 = % escalation of O&M per year between start of commercial operations and an additional 5 years

e_3 = % escalation of O&M per year for the remaining 15 years

then

$$OM_{PV}\ (\$C_e,\ 1980) = \$C\ (P/F,\ i_{ra},\ S-1980)\ [(P/A,\ i_{rb},\ 5) + (P/F,\ i_{rb},\ 5)\ (P/A,\ i_{rc},\ 15)]$$

where

(1) OM_{PV} ($\$C_e$, 1980) = Present Value of Operations and Maintenance cost of component "C" subject to escalation between 1980 and plant retirement, expressed in 1980 dollars.

(2) $C = Initial estimate of annual O&M component "C" cost in 1980 dollars.

(3) (P/F, i_{ra}, S-1980) is factor for determining component cost in year "S" in 1980 dollars.

$$i_{ra} = [(1 + i)/(1 + e_1)] - 1.$$

(4) (P/A, i_{rb}, 5) is the present worth of 5 year escalating annuity starting year "S" and

$$i_{rb} = [(1 + i)/(1 + e_2)] - 1.$$

(5) (P/F, i_{rb}, 5) is the value of C for year (S + 5) in year "S".

(6) (P/A, i_{rc}, 5) is the present worth of 15 year annuity escalating at rate e_3.

In brief, the equation converts the two successive escalating future annuities to their present worth in 1980 dollars.

C. PRODUCT PRICING

Two measures of product price have been derived: the 1980 product price and the UAE cost of service price. The methodology for each is reviewed here.

1. <u>Computation of a "1980 Price"</u>

For certain economic evaluation purposes, it is convenient to define a 1980 price, which has the following interpretation:

(1) In the absence of inflation, assume that the price received is the 1980 price in all time periods.

(2) In the presence of inflation, assume that the price received on each time period is the 1980 price escalated to that time period by the general rate of inflation.

Then, the discounted present value of revenue equals the present value of the plant, as defined earlier.

The 1980 price is computed as follows. Let:

PV	=	present value of the plant in January 1980.
D	=	Nominal discount rate
R	=	Real discount rate
E	=	general rate of inflation = $[(1+D)/(1+R)] - 1$
P_{1980}	=	1980 price of product
MAP	=	module annual production
PV_i	=	present value of i^{th} module
S_i	=	date of start-up of the i^{th} module from January 1980, in years $S_1 = 5.5$ $S_3 = 7.0$ $S_2 = 6.5$ $S_4 = 7.5$

For the TVA coal gasification plant, the 1980 price satisfies the following equation, (assuming all revenue for a year is received at the end of the year; a slightly different answer would be obtained by assuming monthly or continuous revenue)

$$PV_{Facility} = PV_1 + PV_2 + PV_3 + PV_4$$

$$PV_{Revenue} = \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_1+i}} + \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_2+i}} + \sum_{i=1}^{20} \frac{P_{1980} \times MAP}{(1+R)^{S_3+i}}$$

$$+ \sum_{i=1}^{20} \frac{P_{1980} \quad MAP}{(1+R)^{S_4+i}}$$

$$= P_{1980} \times MAP \times \left[\frac{1}{(1+R)^{S_1}} + \frac{1}{(1+R)^{S_2}} + \frac{1}{(1+R)^{S_3}} + \frac{1}{(1+R)^{S_4}} \right] \sum_{i=1}^{20} \frac{1}{(1+R)^i}$$

Evaluating this expression for R = 4.7% (D = 12%; E = 7%);

$$PV = P_{1980} \times MAP \times 37.67$$

or

$$P_{1980} = \frac{PV}{MAP \times 37.67}$$

2. <u>UAE Cost of Service Price</u>

The UAE cost of service is computed using the following three steps:

(1) Costs are escalated according to the TVA design criteria.

(2) Costs are discounted to a 1980 present value using a 12% discount rate.

(3) Costs are annualized over the life of the plant at a 12% rate.

The UAE cost of service price is computed using the same formula as the 1980 product price, using the nominal discount rate rather than the real discount rate, yielding the following expression:

$$PV = UAE \times MAP \times \left[\frac{1}{(1+D)^{S_1}} + \frac{1}{(1+D)^{S_2}} + \frac{1}{(1+D)^{S_3}} + \frac{1}{(1+D)^{S_4}} \right] \sum_{i=1}^{20} \frac{1}{(1+D)^i}$$

Evaluating this expression for D = 12% and

S_1 = 5.5 years S_3 = 7.0 years

S_2 = 6.5 years S_4 = 7.5 years

$$PV = UAE \times MAP \times 14.152$$

or

$$UAE = \frac{PV}{MAP \times 14.152}$$

D. SENSITIVITY ANALYSIS

The easiest way to describe sensitivity analysis is to call it a "what if?" analysis. The original "best value" analysis has shown the product price under estimated conditions of investment, efficiency, operating costs, commercial product slate, and anticipated life. All of these are educated projections but a probability exists that one or all can vary significantly because of unforeseen events. If certain major parameters change, previously acceptable candidates may suffer greatly while alternative projects may become more attractive. Projecting the costs, efficiency, service reliability and value of revenue-producing by-products for a developing technology over a period of some years in the future is uncertain at best.

A sensitivity analysis defines the impact on product price that would be caused by a change in some significant economic factor. It does not define a precise price but instead illustrates the required price <u>if</u> the unexpected changes occur. A decision to accept or reject a potential project, then, must be weighted by full consideration of "best estimate" attractiveness and the probability that the "what if" changes happen. For this section of the study, efforts will be confined to measuring product price changes caused by certain events affecting project parameters.

Table 5.7 of the Design Criteria guidelines presents 10 parameters of the project which may vary. Of these, 5 relate to possible changes in estimated costs and 5 examine a change in construction or production factors, but all 10 impact upon product price.

1. Sensitivity to Cost Factors

The 5 analyses to be performed are:

(1) What if coal costs 50% more than the $1.25/MMBTU used in the base case?

(2) What if the total capital requirements actually amount to 125% of the estimate?

(3) What if operating costs increase to 150% of those estimated?

(4) Previously, the base case only considered coal fines and excess electric power as salable by-products. What if other materials like Sulfur, Sulfuric Acid, Ammonia, Naphtha, Light Oil, Tar, Phenols and/or Methanol can become commercially salable?

(5) What if the assigned cost of capital (12%) is changed to some other value to be determined later?

If coal costs more, product prices will increase significantly because coal is a major cost component of product price. In the performance of this analysis, the "best value" coal component of product-price will be increased by 50% and the new product price or increment will be determined. The resultant sensitivity to coal price change must be weighed against the likelihood that a boost amounting to 50% could occur.

If Capital Costs increase by 25%, there will be a relatively significant change in product price because the project involves heavily capital-intensive facilities. The determination will be made by increasing best value capital cost contributions to product price by 25%.

A 50% increase in operating costs, while dramatic in apparent impact, will affect the product price to only a small extent. As before, the operating cost contribution will be increased by 50% from the best value and the impact determined.

If other by-products become commercially salable, the impact may be significant and particularly for sulfur and ammonia. However, their contribution to revenues which acts as a reduction of costs assigned to the gaseous product must be weighed against incremental capital and operating cost which will be required to produce merchantable products.

If the cost of capital changes from 12%, as furnished, to some other value, the impact upon product price could be significant but would depend upon the value of the incremental cost rate. To determine this factor, the base-calculations would be adjusted to reflect the change time-value of money.

2. Sensitivity to Process Related Factors

The 5 process parameters for investigation are:

(1) Plant Capacity Factor reduction.

(2) Variation of Design/Construction Period.

(3) Extension of projected plant life.

(4) Change in sulfur emission limits.

(5) Variation in product gas discharge pressure.

If the plant cannot sustain operations at the prescribed 90% Plant Factor, there will be substantial increases in the product price. The volume of annual product will be linearly reduced, coal and chemical annual costs will decline, but the capital related costs remain constant in terms of dollars per year. The product price, per MMBTU, will increase almost inversely with the capacity factor as the following simplified rationale indicates. Assume the coal, chemicals unit contributions to product cost remain constant but annual operating and maintenance expenses and capital charges increase because the same dollars per year are allocated over a substantially reduced volume of product.

If the plant can be built quicker or takes longer to complete, the magnitude of product price impact is not easily definable. As would be anticipated, acceleration yields lower costs and prices while delay increases the costs and prices. However, measured against competitive alternatives which possess their own inherent escalation rates, the comparative economics may indicate virtues of either schedule.

If the plant can operate effectively for an additional 5 or 10 years, the impact on product price requirements may be minimal. The difference in the capital recovery factor, allocated to annual operations, amounts to a reduction in annual costs of some 0.63% of the capital requirements for a 25 year life, measured against a base approximately 13%. Extended to the 30 year life, the total reduction (20 years vs. 30 years) would be less than 1% from the base 13% allocation.

The final two sensitivity analyses relating to sulfur emissions and discharge pressures would or could be significant but require an incremental cost analysis and evaluation because each could affect total capital requirements and operating costs. It is not readily visible what the extent may be. Investigation would be required for operating condition changes, incremental fuel/power requirements, possible product volume changes and any other sensitive parameters.

APPENDIX A

Time-Value Factors for Periodic Compounding

This appendix contains tables of time-value factors for periodic compounding. The following nine factors are tabulated for interest rates from 1 to 20%.

- *The Present Worth (P) of a Future Amount (F)*

$$(P/F, i\%, N) = \frac{1}{(1+i)^N}$$

- *The Future Worth (F) of a Present Amount (P)*

$$(F/P, i\%, N) = (1+i)^N$$

- *An Annuity (A) from a Present Amount (P)*

$$(A/P, i\%, N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

- *An Annuity (A) for a Future Amount (F)*

$$(A/F, i\%, N) = \frac{i}{(1+i)^N - 1}$$

- *The Present Worth (P) of an Annuity (A)*

$$(P/A, i\%, N) = \frac{(1+i)^N - 1}{i(1+i)^N}$$

- *The Future Worth (F) of an Annuity (A)*

$$(F/A, i\%, N) = \frac{(1+i)^N - 1}{i}$$

- *An Annuity (A) from a Linear Gradient (G)*

$$(A/G, i\%, N) = \frac{1}{i} - \frac{N}{(1+i)^N - 1}$$

- *The Present Worth (P) of a Linear Gradient (G)*

$$(P/G, i\%, N) = \frac{1}{i}\left[\frac{(1+i)^N - 1}{i(1+i)^N} - \frac{N}{(1+i)^N}\right]$$

- *The Future Worth (F) of a Linear Gradient (G)*

$$(F/G, i\%, N) = \frac{1}{i}\left[\frac{(1+i)^N - 1}{i} - N\right]$$

APPENDIX B

BASIS AND ASSUMPTIONS FOR ECONOMIC ASSESSMENTS

All data in this Appendix were extracted from the February 22, 1980 Design Criteria for Conceptual Designs & Assessments of TVA's Coal Gasification Demonstration Plant.

5.1 Module life: 20 years after startup (as defined by present schedule) with no salvage value. No cost assumed for disassembly and disposal.

5.2 Module service or stream factor: 90 percent

5.3 Capital and operating cost estimates: Stated in January 1980 dollars

5.4 Financing: Government appropriations (disregard income and property tax)

5.5 Economic evaluation rate: 12 percent

5.6 General and administrative expense: 5 percent of total operating and maintenance cost

5.7 Schedule of cash flow by year: Breakdown of plant subsystems by both capital and operating expenses

5.8 Product gas cost: To be presented as a levelized unit cost ($/MMBtu) over economic life of plant

5.9 Cost of delivered coal: 1980 Value, $/MMBtu $1.25
Escalate each year to the end of 1985 by 9%
Escalate each year from 1986 to end of 1995 by 8%
Escalate each year from 1996 onward by 7%

5.10 Limestone cost: $13/ton as received (escalate at same rate as coal)

5.11 Coke (for gasifier starter) cost: $60/ton, sized (escalate at same rate as coal).

5.12 Byproduct credit: No credit for byproduct except for excess electricity and coal fines (see values below). See exhibit for byproduct credit for sensitivity analysis case.

BASIS AND ASSUMPTIONS FOR ECONOMIC ASSESSMENTS
(CONTINUED)

5.13 Excess electricity sales: Same as cost to plant

5.14 Coal fine sales: 80 percent of ROM coal cost

5.15 Land cost*: $3,000/acre

5.16 Clearing and grubbing*: $2,000/acre

5.17 Excavation*: (a) earth $1.50/cubic yard (b) rock $10/cubic yard

5.18 Fill (compacted)*: $3/cubic yard

5.19 Electric power cost: See Table B.1

5.20 Construction labor: See Table B.2

5.21 Maintenance labor: See Table B.3

5.22 Operating labor: See Table B.4

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* 1980 cost (unless stated otherwise escalate according to Table B.5).

TABLE B.1. ELECTRIC POWER COST

YEAR	ENERGY CHARGE MILLS PER KWH	DEMAND CHARGE $/KW[1] PER MONTH
1980	17.47	4.80
1981	20.59	5.85
1982	21.82	6.31
1983	22.92	6.96
1984	24.25	7.53
1985	26.05	7.94
1986	26.14	8.81
1987	26.32	9.84
1988	28.39	9.96
1989	27.40[2]	11.73
1990[3]	28.17[2]	12.92

1/ Min. peak for each respective month.

2/ Project lower values reflect the manner in which the TVA power system expansion is planned.

3/ The cost of power and demand charges for years beyond 1990 shall be assumed to escalate at a rate of 7.76 percent per year.

TABLE B.2. CONSTRUCTION LABOR COST[1/]

CRAFT	RATE/HOUR
BOILERMAKERS	$16.00
BRICKLAYERS	12.00
CEMENT MASONS	11.00
MILLWRIGHTS	12.50
CARPENTERS	11.50
PAINTERS	12.50
ELECTRICIANS	14.00
IRONWORKERS	13.50
MACHINISTS	11.00
G & D MECH	12.00
OUTSIDE MECH	12.00
SHEETMETAL	14.50
STEAMFITTERS	14.50
TEAMSTERS	9.00
LABORERS	8.00
OPEN ENGR	11.00

1/ Rates rounded to a whole or half-dollar. Construction T&L wages and fringe benefits, 1980 (composite of foremen and journeymen).

TABLE B.3. MAINTENANCE LABOR[1/]

CLASSIFICATION	PLANT MAINTENANCE	TURNAROUND MAINTENANCE
FOREMAN		
ASBESTOS	17.00	19.50
BOILERMAKER	18.00	21.00
ELECTRICIAN	16.00	19.00
IRONWORKER	15.00	18.00
MACHINIST	13.50	16.00
SHEETMETAL WORKER	16.00	19.50
STEAMFITTER	16.00	19.50
CARPENTER	13.50	16.00
PAINTER	13.50	16.00
TRUCK DRIVER	11.00	13.00
LABORER	10.00	12.00
JOURNEYMEN		
ASBESTOS WORKER	15.00	18.00
BOILERMAKER	16.00	18.50
ELECTRICIAN	14.50	17.50
IRONWORKER	13.50	16.00
MACHINIST	12.50	14.50
SHEETMETAL WORKER	15.00	17.50
STEAMFITTER	15.00	17.50
CARPENTER	12.50	14.00
PAINTER	12.00	14.00
TRUCK DRIVER	10.00	11.50
LABORER	8.50	10.00

1/ Schedule of hourly trades and labor rates; 1980 rates. Rates rounded to a whole or half-dollar. Values include fringe benefits.

TABLE B.4. OPERATING LABOR[1/]

		ANNUAL SALARY RATE, $
1.	PLANT SUPERINTENDENTS OFFICE	
	PLANT SUPERINTENDENT	40,800
	ASSISTANT PLANT SUPERINTENDENT	37,400
	ADMINISTRATIVE SERVICES SUPERINTENDENT	28,000
	ADMINISTRATIVE OFFICER	19,200
	STORES RECORDS CLERK	14,100
	PAYROLL CLERK	15,200
	CLERK	12,700
	CLERK-TYPIST	10,400
2.	PLANT OPERATIONS SECTION	
	PLANT OPERATING SUPERVISOR	34,500
	CLERK-STENOGRAPHER	12,700
2A.	PLANT OPERATIONS	
	SHIFT ENGINEER	27,600
	ASSISTANT SHIFT ENGINEER	22,600
	SENIOR SWITCH BOARD OPERATOR	20,300
	UNIT OPERATOR	20,300
	ASSISTANT UNIT OPERATOR	17,000
	AUXILIARY OPERATOR	15,300
	STUDENT INSTRUCTOR	26,900
	STUDENT GENERAL PLANT OPERATOR	14,200
2B.	YARD OPERATIONS	
	YARD OPERATIONS SUPERVISOR	24,000
	COAL HAULING FOREMAN	14.00*
	HEO PR	13.00*
	HEO PR APPRENTICE	11.00*
	COAL TOWER FOREMAN	14.00*
	COAL CAR DUMP OPERATOR	14.00*
	TRACK FOREMAN	14.00*
	LABORER	8.50*
	STUDENT PLANT LABORER	7.50*

1/ Rates and structure based on representative TVA coal-fired power plant (see Table B.5). Values listed are 1980 rates. Annual rates are convertible to hourly rates by dividing the annual rates by 2,080 (52 weeks times 40 hours). For total annual labor cost add 42 percent for fringe benefits.

* 1980 Hourly wages and fringe benefit rates for trades and labor.

TABLE B.4. OPERATING LABOR[1/] (CONTINUED)

3.	PLANT RESULTS SECTION	ANNUAL SALARY RATE, $
	PLANT RESULTS SUPERVISOR	34,500
	ASSISTANT PLANT RESULTS SUPERVISOR	28,000
	INSTRUMENT UNIT FOREMAN	21,600
	INSTRUMENT MECHANIC	14.50*
	INSTRUMENT MECHANIC APPRENTICE	11.00*
	MECHANICAL UNIT FOREMAN	21,600
	ENGINEERING AIDE	16,200
	CHEMICAL UNIT FOREMAN	21,600
	CHEMICAL LAB ANALYST	16,200
	MATERIALS TESTER	16,200
4.	MISCELLANEOUS	
	BOILERMAKER FOREMAN	22,700
	BOILERMAKER	19,200
	BOILERMAKER APPRENTICE	15,873
	JANITOR (SENIOR)	14,665
	JANITOR	13,500

1/ Rates and structure based on representative TVA coal-fired power plant (see Table B.5). Values listed are 1980 rates. Annual rates are convertible to hourly rates by dividing the annual rates by 2,080 (52 weeks times 40 hours). For total annual labor cost add 42 percent for fringe benefits.

* 1980 Hourly wages and fringe benefit rates for trades and labor.

TABLE B.4. OPERATING LABOR[1/] (CONTINUED)

ANNUAL CLASSIFICATION	ANNUAL SALARY[1/]
LABORER (UNCLASSIFIED)	
PLANT LABORER	$13,100
AMMONIA LABORER	
BAGGING AND LOADING LABORER	
PILOT PLANT LABORER	
PILOT PLANT OPERATOR TRAINEE	
RELIEF OPERATING LABORER	
WATER PLANT LABORER	
CLASS C OPERATOR	$15,200
BAGGER AND WEIGHER	
CONVEYOR OPERATOR	
FERTILIZER LOADER	
PILOT PLANT OPERATOR, C	
RELIEF OPERATOR, C	
CLASS B OPERATOR	$16,400
ACID PUMPER AND ADJUSTER	
AIR SEPARATION AUXILIARY OPERATOR	
AMMONIA PLANT AUXILIARY OPERATOR	
BOILER HOUSE AUXILIARY OPERATOR	
COAL HANDLING AND UTILITY OPERATOR	
GAS PURIFICATION AND SULPHUR RECOVERY AUXILIARY OPERATOR	
GRANULATOR SYSTEM AUXILIARY OPERATOR	
LIQUID FERTILIZER UNIT AUXILIARY OPERATOR	
LOADING CHECKER	
NITRIC ACID AUXILIARY OPERATOR	
OVERHEAD CRANE OPERATOR	
PILOT PLANT OPERATOR, B	
RELIEF OPERATOR, B	
SLURRY-PREPARATION-GASIFICATION AUXILIARY OPERATOR	
STORAGE AND LOADING OPERATOR	
WASTE WATER TREATMENT AUXILIARY OPERATOR	

ANNUAL CLASSIFICATION	ANNUAL SALARY[1/]
CLASS A OPERATOR	$17,900
AIR SEPARATION CONTROL OPERATOR	
AMMONIA PLANT CONTROL OPERATOR	
AMMONIA PLANT PROCESS OPERATOR	
AMMONIA STORAGE AND DISTRIBUTION OPERATOR	
BOILER HOUSE OPERATOR	
GASIFICATION-PURIFICATION CONTROL OPERATOR	
GRANULATOR SYSTEM OPERATOR	
LIQUID FERTILIZER UNIT OPERATOR	
NEUTRALIZER AND CONCENTRATOR OPERATOR	
NITRIC ACID OPERATOR	
PILOT PLANT OPERATOR, A	
RELIEF OPERATOR, A	
UREA UNIT CONTROL OPERATOR	
UREA UNIT PROCESS OPERATOR	
WATER PLANT OPERATOR	
FOREMAN	$21,200
ACID UNIT FOREMAN	
AMMONIA FROM COAL FOREMAN	
BAGGING AND LOADING FOREMAN	
PILOT PLANT SHIFT FOREMAN	
UREA UNIT FOREMAN	
UTILITIES FOREMAN	
CHEMICAL PLANT FOREMAN	$25,500
OPERATOR TRAINEE	
CHEMICAL PLANT OPERATOR TRAINEE I--A	$13,500
CHEMICAL PLANT OPERATOR TRAINEE I--B	$13,900
CHEMICAL PLANT OPERATOR TRAINEE II	$15,200
CHEMICAL PLANT OPERATOR TRAINEE III	$16,400

1/ TVA schedule of trades and labor classes and rates of pay schedule C. Regular operating work--Division of Chemical Operations and Division of Chemical Development. Values listed are 1980 rates. Annual wages are convertible to hourly rates by dividing the annual rates by 2,080 (52 weeks times 40 hours). For total annual labor cost add 42 percent for fringe benefits.

TABLE B.5. ESCALATION RATES

CONSTRUCTION: T&L WAGES AND FRINGE BENEFITS

RATES ON		HIGHER THAN
1/1/81	ARE ESTIMATED TO BE 8.5%	1/1/80
1/1/82 THRU 1/1/86	ARE ESTIMATED TO BE 9.0%	EACH PREVIOUS JANUARY 1
JANUARY 1 EACH YEAR	ARE ESTIMATED TO BE 8.0%	PREVIOUS JANUARY 1

MAINTENANCE: ANNUAL T&L SALARIES AND FRINGE BENEFITS

SALARIES ON		HIGHER THAN
1/1/81	ARE ESTIMATED TO BE 9.0%	1/1/80
1/1/82 THRU 1/1/86	ARE ESTIMATED TO BE 8.5%	EACH PREVIOUS JANUARY 1
JANUARY 1 EACH YEAR	ARE ESTIMATED TO BE 7.5%	PREVIOUS JANUARY 1

PLANT OPERATORS: ANNUAL SALARY POLICY SALARIES AND FRINGE BENEFITS

SALARIES ON		HIGHER THAN
7/1/80 THRU 7/1/86	ARE ESTIMATED TO BE 8.0%	EACH PREVIOUS JULY 1
JULY 1 EACH YEAR	ARE ESTIMATED TO BE 7.5%	PREVIOUS JULY 1

CONSTRUCTION: MATERIALS AND EQUIPMENT*

PRICES ON		HIGHER THAN
1/1/81	ARE ESTIMATED TO BE 10%	1/1/80
1/1/82 THRU 1/1/86	ARE ESTIMATED TO BE 9.5%	EACH PREVIOUS JANUARY 1
JANUARY 1 EACH YEAR	ARE ESTIMATED TO BE 8.0%	PREVIOUS JANUARY 1

1/ Contractor should recommend to TVA the use of higher escalation rates for materials that have historically been subject to abnormally high price increases.

TABLE B.6. SENSITIVITY ANALYSIS APPLIED TO COST OF GAS

		INCREMENT
1.	COAL COST	+ 50%
2.	CAPITAL COST VARIATION 1/	+ 25%
3.	OPERATING COSTS	+ 50%
4.	SERVICE FACTORS (BASE CASE = 90%)	80%, 70%, 60%
5.	BYPRODUCT VALUE	SEE TABLE BELOW
6.	DESIGN/CONSTRUCTION PERIOD PER MODULE	± 1 YEAR
7.	OPERATING LIFE YEARS	+ 5, + 10
8.	SULFUR IN PRODUCT GAS 2/	TO 1.0 PPM
9.	PRODUCT GAS PRESSURE	MAX = 800 psi MIN = 200 psi 3/
10.	ECONOMIC EVALUATION FACTOR	T.B.D.

BYPRODUCT VALUES FOR SENSITIVITY ANALYSIS 4/

SULFUR, \$/TON	70.00
SULFURIC ACID, \$/TON	60.00
AMMONIA (ANHYDROUS), \$/TON	130.00
NAPHTHA (120-320°F), \$/GAL	0.80
LIGHT OIL (300-700°F), \$/GAL	0.80
TAR (700°F+), \$/GAL	0.60
PHENOLS, \$/GAL	0.75
COAL FINES, \$/TON	80% OF ROM COAL COST
EXPORT POWER, ¢/kWh	SAME AS COST TO PLANT
METHANOL, ¢/GAL	35

1/ Contractor may recommend alternate increment and suggest a listing of equipment for which contingencies are to apply.

2/ Contractor is to use factored estimates for determining gas cost at sulfur level below sulfur breakpoint.

3/ Or lowest practical value above 200 psi permitted by design constraints (contractor to recommend value).

4/ Except for coal fines and electric power, escalate byproduct values at same rate as coal prices.

APPENDIX C
DEMONSTRATION OF COST ESTIMATION AND ECONOMIC EVALUATION METHODOLOGY

A. INTRODUCTION

In order to depict the manner in which the cost estimation and economic evaluation methodology is executed, the following example has been constructed. The cost of hypothetical process vessel subsystem is estimated using the Guthrie Cost Estimation Technique*. The Guthrie method is based upon cost patterns and relationships which have emerged from the experience of over 50 refinery and chemical processing plants. From this data base, the critical cost driver variables and the cost estimating relationship between them have been derived for the major system components of a process plant. This example demonstrates how these cost estimating relationships can be used to generate an estimated cost for a planned process plant system or subsystem such as a process vessel.

It is then demonstrated how other capitalized costs associated with the actual construction and planned operation of a system are estimated to calculate the total capital requirements of the plant.

This is followed by a set of hypothetical assumptions which are used to demonstrate the manner in which the levelized, or uniform annual equivalent, cost of services is calculated.

B. SUBSYSTEM COST ESTIMATION FOR TOTAL CAPITAL REQUIREMENTS

1. Cost of Hypothetical Process Vessel

The equipment cost of a process vessel shell is a function of many factors. The base equipment cost (B) depends largely on three cost drivers which include:

(1) the height or length of the vessel,

(2) the diameter of the vessel, and

(3) the vertical or horizontal fabrication of the vessel.

This base cost must be adjusted to reflect the type of material of which the shell is to consist, and the internal pressure it is designed to sustain. Finally, the adjusted equipment estimate must be expressed in present dollars, which requires that the estimate calculated from historical cost data be escalated to reflect present price levels. This cost estimation procedure can be summarized as:

Base Cost (B) x Shell Material Factor (F_M) x Internal Pressure Pressure (F_P) x Escalation Index (F_E) = Process Vessel Shell Equipment Cost (E)

For example: assume a hypothetical process vessel with the following characteristics:

Height T-T	Diameter - Feet	Material	Operating Pressure
40	8'	SS-316 clad	500 psig

The Base Cost is estimated as a function of the height and diameter, and an assumption that vertical fabrication is used. From updated (to 1978) versions of the cost estimating relationships shown in Guthrie (p. 151), the base vesel cost is determined to be $39,000.

Description		Factor	B	E
Base Equipment Cost (B)	=		$39,000 ('78$)	
F_M (Shell Material Factor) for Stainless Steel 316 clad (p. 150, Guthrie)	=	2.6		
F_P (Pressure Factor) for 500 psig (p. 150, Guthrie)	=	2.8		
F_E (Escalation Index) for adjusting 1978 to January '80 dollars	=	1.14		
Adjusted Equipment Cost (E)	=			$323,668 ('80$)

2. Cost of Related Subsystem Equipment

A process vessel shell does not stand alone but includes an assortment of other equipment. These other equipment costs must be added to the cost estimate. For this hypothetical process vessel, for example, a critical item is trays. The base cost of a tray is a function driven by tray diameter and stack height. To this base cost are applied factors to reflect tray spacing (F_S), tray type (F_T), and tray material (F_M). This can be expressed as:

Tray Cost \$ = [Base Cost (B) x ($F_S + F_T + F_M$)] x Escalation Index (F_E)

For example: assume the following characteristics for this hypothetical pan.

Tray Diameter	Tray Stack Height	Tray Spacing	Tray Type	Tray Material
8'	14'	24"	Sieve	Stainless Steel

Referring to Guthrie (p. 152) yields:

Description		Factor	B	E
Base Equipment Cost (B)	=		\$3600 ('78\$)	
F_S (Tray Spacing Factor) for 24" spacing	=	1		
F_T (Tray Type) for Sieve tray	=	0		
F_M (Tray Material) for Stainless Steel	=	1.5		
F_E (Escalation Index) for '78 to '80 dollars	=	1.14		
Adjusted Equipment Cost (E)	=			\$10,260 ('80\$)

3. Estimating Total Subsystem Equipment Cost

In the manner above all the major equipment components of a system or subsystem can be identified and costed. Finding total equipment costs requires only summation. An effort should be made to total both

B (Base Costs) and E (Adjusted Equipment Costs) as both estimates are required for later cost calculations of materials (M) and Labor (L).

For this example:		B	E
Subsystem Equipment:		('78$)	('80$)
(1)	Process Vessel	$39,000	$323,668
(2)	Tray	$ 3,600	$ 10,260
	Subtotal Equipment (E) =	$42,600	$333,928

4. Estimating Field Material Costs

Installation of equipment requires additional materials such as piping, concrete, steel, instruments, electrical, insulation, and paint. Guthrie has established factors for each of these field material subaccounts for a variety of process equipment (refer to Guthrie p. 154). These factors typically represent a given percentage of the base cost (B) of the equipment. As indicated in the example below, however, it is occasionally appropriate to apply the factor as a percentage of the adjusted equipment cost (E) so as to include consideration of some additionally relevant factor which that estimate contains. Specifically, inasmuch as the process vessel is stainless steel, much of the piping must be stainless steel as well; thus, the piping factor is taken as a percentage of E which includes the F_M (materials factor). Note that the piping factor applied to E is additionally factored by .75 to allow for the fact that not all of the piping will necessarily be stainless steel. Piping is also calculated as a percentage of B to keep the B cost account complete. None of the other subaccounts are sensitive to the additional factors which have been applied to the base costs (B) to derive (E); therefore, they are applied directly to B. An important exception is that all costs need to be escalated to present dollars so that when estimating on the basis of B, the escalation factor must be used to derive E. The factors are summed in both E and B summations for later use in calculating installation labor (L).

Using the updated subaccount factors from Guthrie (p. 154) for this example yields:

Description	% of B	% of E	B ('78$)	E ('80$)
Piping	81.5	81.5X.75	34,719	204,113
Concrete	9.6		4,090	4,663
Structural Steel	9.6		4,090	4,663
Instrumentation	11.0		4,686	5,342
Electrical	4.3		1,832	2,088
Insulation	8.3		3,536	4,031
Paint	1.2		511	583
Subtotal of Materials (M)			53,464	225,483

5. Subtotalling Total Materials (E+M)

Subtotalling E+M will be of value later in the costing procedure in calculating a labor/materials ratio. In this example:

	B ('78$).	E ('80$)
Subtotal Equipment (E)	42,600	333,928
Subtotal Materials (M)	53,464	225,483
Total (E+M)	96,064	559,411

6. Estimating Installation Labor (L)

An estimate for the cost of labor to install the equipment is taken directly as a factor applied to the base equipment cost B. Referring to Guthrie (p. 154) for the factor relevant to this example yields:

Installation Labor (L) = 1.058 x B($42,600) = $45,070

This also should be expressed in 1980 dollars yielding

= $45,070 x 1.14 ($F_E$) = $51,380

7. Calculating Total Direct Costs (E+M+L)

Total Direct Costs are summed to be used as a basis for the calculation of indirect costs. For this example:

E = $333,928

M = $225,483

L = $ 51,380

Total Direct Costs (TDI) = E+M+L = $610,791

8. Calculating Indirect Construction Costs

There are a number of other costs associated with the installation of a system including construction overhead, engineering costs, home office costs, freight charges, taxes and insurance. These costs are estimated as a percentage factor of total direct costs. For this example, Guthrie recommends (p. 154) a total indirect factor of .38 which has been updated to .45. Assuming that the indirect cost factors are split as follows: Construction Overhead (0.29), Engineering/Home Office (0.09), and Freight/Taxes/Insurance (0.07) then indirect costs are:

Description		Factor		Indirect Costs
Construction Overhead	=	.29 x TDI	=	$177,129
Engineering/Home Office	=	.09 x TDI	=	54,971
Freight/Taxes/Insurance	=	.07 x TDI	=	42,755
Total Indirect Costs	=	.45 x TDI	=	$274,855

9. Calculating Total Direct + Indirect Costs

This summation produces Guthrie's so-called total modular cost (no reference to TVA use of module). The modular costs for systems and subsystems are used to calculate process and project contingencies, owner's costs, and contractor fees to generate the total facility investment.

For this example:

Total Direct Costs (TDI)	=	$610,791
Total Indirect Costs (IND)	=	274,855
Total System Capital Investment	=	$885,645

C. BUILD-UP OF TOTAL CAPITAL REQUIREMENTS FOR A MEDIUM - BTU GAS MODULE FROM SYSTEM AND SUBSYSTEM CAPITAL COST ESTIMATES

1. Calculating Total Facility Investment

Many capital requirements are not specific to individual systems, and therefore are taken as a factor of the summed costs for the individual systems. The project contingency allowance is applied to the summed systems cost to yield the Total Installed Facility Investment. To this are

added factors for owner's costs incurred and contractor's fees. The subtotal of the summed system costs and the factors applied to that sum yield the total investment necessary for construction of the facility. The operation for this estimate can be expressed as

$(\sum_{n}^{1}$ Systems Costs for Systems 1 to N + Project Contingency Factor) + Owner's Cost Factor + Contractor's Fee Factor = Total Facility Investment.

For this example:

DESCRIPTION	E	M	L	Indirects	Total
Process Vessel	333,928	225,483	51,380	274,855	885,646
.					
.					
.					
Other Systems	K_1	K_2	K_3	K_4	K_5
Total of System Capital Investments (TSCI)	$333,928+K_1$	$225,483+K_2$	$51,380+K_3$	$274,855+K_4$	$885,646+K_5$

Project Contingency (PC) (Factor = .15 of subtotal above)	$132,847 + 0.15K_5$
Total Installed Facility (TIF = TSCI+PC)	$1,018,493 + 1.15K_5$
Contractor's Fees (CF) (Factor = 4% of TSCI+PC)	$40,740 + 0.05K_5$
Owner's EG&A (Factor = 2% of TSCI+PC+CF)	$21,185 + 0.02K_5$
Subtotal: Total Facility Investment (TFI)	$1,080,418 + 1.22K_5$

Assumptions are from the BDM/Mittelhauser methodology (p. 8) as follows:

(1) Project Contingency = 15%

(2) Contractor's Fee = 4%

(3) Owner EG&A = 2%

2. Calculating Other Capital Costs

Other costs which must be capitalized include:

(1) Paid-Up Royalties - Estimated as a percentage of the total facility investment. In this case a factor of 0.005 is used (assumption is taken from EPRI AF-916, page 21).

(2) Start-Up and Test - Estimated by assuming that the operations and maintenance costs associated with start-up and test escalate

linearly from 0 percent of the estimated O&M costs for full production at the beginning of start-up to 100 percent of full production O&M costs at the completion of the test period. Based on this assumption, the average percent of full production costs required for the start-up and test period can be calculated and used for this estimate.

In this case, it is estimated that SU/T is equivalent to 65 percent of Annual O&M costs. For this example, it is simply expressed as a quantity SUT.

(3) Allowance For Funds Used During Construction (AFUDC) - It is estimated so as to include the cost of funds used during the construction period. It is estimated by using the construction schedule to calculate the percent of cumulative construction in each year of construction, deriving the average expenditures for the period, and applying the cost of capital rate of 12 percent (refer to BDM/MIT, page 9).

For this example, it will simply be expressed as a factor of total facility investment.

Adding these other capitalized costs to the total Facility Investment yields an estimate for the total depreciable investment.

Continuing the example:

Other Capitalized Costs:

Paid-Up Royalties (0.005 of TFI)	=	5,402 + $.006K_5$
Start-Up and Test (~65% Annual OSM)*	=	\$SUT
AFUDC (An assumed factor of .08 applied to TFI)*	=	86,433 + $0.10K_5$
Subtotal of Above	=	\$ 91,835 + $0.106K_5$ + \$SUT
Subtotal of Depreciable Investment	=	\$1,172,253 + $1.326K_5$ + \$SUT

*The assumptions are:

(1) One-year complete production, achieve design specification production 65 percent annual O&M.

(2) Simplified 40 percent, 60 percent - 2-year construct.

3. Estimating Working Capital and Other Non-Depreciable Costs

Working capital includes an accounting of the initial change of chemicals and catalysts necessary to run the facility, sufficient materials for a short period of operations, provision for spare parts, and sufficient cash for operations. The assumptions and estimates for this example include:

(1) Initial Charge (based on operating criteria, expressed here as an undefined quantity)

$ IC

(2) Inventory of Materials (calculated as a given number of days of feedstock and operating supplies based on Annual O&M cost estimate. Expressed here as an undefined quantity).

$ M

(3) Inventory of Spare Parts (calculated as 1 percent of E&M) (refer to BDM/MIT, page 11).

$\$ 5,594 + .01(K_1+K_2)$

(4) Minimum Cash Requirement (calculated in terms of a given number of days of O&M expenses, usually 45,) expressed here as an undefined quantity.

$MCR

The cost of land is also a non-depreciable capital cost and should be included with other non-depreciable costs. It is expressed for this example simply as

$ L

4. Total Capital Requirement Summation

The estimate of total capital requirements will include the total facility investment, other capitalized depreciable costs, and all non-depreciable capital costs. For this example:

$$\text{Total Capital Requirement} = (\$1.18 \times 10^6 + 1.33K_5) + \$SUT + \$IC + \$M + \$5,594 + .01\,(K_1 + K_2) + \$MCR$$

D. CALCULATION OF LEVELIZED OR UNIFORM ANNUAL EQUIVALENT COST OF SERVICE

The general approach to be used in calculating the uniform annual equivalents for the cost of service was provided on the methodology. A hypothetical example distinct from that used previously has been assumed to demonstrate the general application of that methodology.

Assume the following costs and assumptions:

Depreciable Investment (DI)	=	$\$1,000 \times 10^6$
Non-Depreciable Investment (NDI)	=	$\$ \ 100 \times 10^6$
Total Capital Requirement	=	$\$1,100 \times 10^6$

Operating and Maintenance Expenses First Year $\$100 \times 10^6$

O&M costs escalate, as of 1-1, at 9 percent for second & third year

O&M costs escalate, as of 1-1, at 8 percent for fourth & fifth year

Project Life = 5 years

Straight Line Depreciation Over 5 years with zero salvage

Cost of Capital, Discount Rate - 12 percent

Annual Payments are assumed to be made on 12-31 of each year.

Using these assumptions the following schedule of costs can be constructed:

(In Millions of Dollars)

YEAR	1	2	3	4	5
O&M (with escalation)	$100	$109	$118.81	$128.31	$138.58
Depreciation (straight-line)	200	200	200	200	200
Return on Dep. Investment	120	96	72	48	24
Return on NDI	12	12	12	12	12
Subtotal Return	132	108	84	60	36
Total Cost of Service	$432	$417	$402.81	$388.31	$374.58

The present value of this future sum =

$$\sum_{n=1}^{5} \text{cost of service}/(1+i)^n = \$1,464 \times 10^6$$

To find the Uniform Annual Equivalent of this cost of service, the present worth is converted to an annuity extending over 5 years.

$$PW \cdot (A/P)_5^{12\%} = \$1,464 \times 10^6 \cdot \left[\frac{i(1+i)^n}{(1+i)^n-1}\right] = \quad \$406.18 \times 10^6$$

From this amount is deducted the value of the working capital which is to be recovered at the end of the period. This is done by converting the NDI to an annuity from a future amount. This is:

$$NDI \cdot (A/F)_5^{12\%} = \left(\$100 \times 10^6\right)\left[i/(1+i)^n-1\right] = \$15.74 \times 10^6$$

The net cost of service (UAE) $=$ $\$390.44 \times 10^6$

The Uniform Annual Equivalent can be arrived at in a different manner when it proves to be too difficult to schedule costs because of a long life-time and changing escalation rates. The example below is closer to the method actually to be used in the present effort. In this method the UAE of O&M and capital recovery are dealt with separately.

The UAE of O&M is dealt with first. As the methodology indicates, the logic for deriving the UAE (O&M) is to consider the series of O&M annual costs which are subject to differing escalation rates as separate annuities. Each annuity reflects the escalation rate specified for that time period, then each is brought to present value. The present worth of the annuities is then levelized over the life of the facility by converting the present amount to an annuity again. For the example below,

$i = 12\%$	$n = 5$	(A/P)	= Annuity from present sum
$e_1 = 9\%$	$n_1 = 3$	(P/A)	= Present value of an annuity
$e_2 = 8\%$	$n-n_1 = 2$	(P/F)	= Present value of a future amount

$$UAE\ (O\&M) = O\&M \cdot (A/P,\ i,\ n) \cdot \Big[(P/A,\ e_1,\ i,\ n_1) + (F/P,\ e_1,\ n_1-1) \cdot (F/P,\ e_2,\ 1) \cdot (P/F,\ i,\ n_1) \cdot (P/A,\ e_2,\ i,\ n-n_1)\Big]$$

To perform this calculation

$$(P/A,\ e_k,\ i,\ n_k) = \frac{\left[\frac{1 + e_k}{1 + i}\right]^{n_k} - 1}{(e_k - i)}$$

and

$$(F/P,\ e_k,\ n_k) = (1 + e_k)^{n_k}$$

and

$$(P/F,\ i,\ n_k)$$

and

$$(A/P,\ i,\ n_k)$$

are customary equations given in Appendix A.

$$\text{UAE (O\&M)} = (\$100 \times 10^6) \left[\frac{0.12\ (1.12)^5}{(1.12)^5 - 1}\right] \cdot \left[\frac{(1.09/1.12)^3 - 1}{(0.09 - 0.12)} + (1.09)^2(1.08)(1/1.12)^3 \cdot \frac{\left[\frac{1.08}{1.12}\right]^2 - 1}{(0.08 - 0.12)}\right]$$

$$= (\$100 \times 10^6)\ (0.2774097)\ [(2.607464) + (1.188)(0.769)(1.75)]$$

$$= \$116.77 \times 10^6$$

The Uniform Annual Equivalent for Capital Recovery is derived:

$$\text{UAE(CR)} = \$DI\ (A/P)_n^i + \$NDI \cdot i$$

$$= (\$1{,}000 \times 10^6) \cdot (0.2774097) + (\$100 \times 10^6) \cdot (0.12)$$

$$= \$289.4097 \times 10^6$$

The Uniform Annual Equivalent of the cost of service is then

$$\text{UAE (cost of services)} = \text{UAE (O\&M)} + \text{UAE (CR)}$$

$$= \$406.18$$

The deduction of the UAE for Working Capital Recovery is expressed:

$$\text{UAE (Working Capital Recovery)} = \$\text{Working Capital} \cdot (A/F)_n^i = (\$100 \times 10^6)(0.1574)$$

$$= \$15.74 \times 10^6$$

$$\text{NET UAE (Cost of Service)} = \text{UAE (O\&M + CR - WC)}$$

$$= \$390.44 \times 10^6$$

APPENDIX D
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